POTENTIAL DROP IMAGING TECHNIQUE FOR SENSITIVE NDE OF SMALL SURFACE CRACKS

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Abstract

This paper reports the potential drop technique as an imaging tool for the clear identification and sensitive evaluation of very small surface cracks. The distributions of d-c potential drop around the surface cracks are obtained by scanning the closely coupled probes potential drop sensor, and a methodology for evaluating a 3-D crack from the potential drop profiles measured across and along the crack is developed. The capability of the potential drop imaging technique is clarified by demonstrating the evaluation of a real fatigue crack.

1. Introduction

The potential drop techniques are very useful for nondestructive evaluation (NDE) of cracks in actual structures. The potential drop techniques use four probes: a set of two probes for current input and output, and another set of two probes for measuring the potential drop. In the case of usual method of evaluation, the potential drop is measured near the crack, and the current input and output probes are located at a large distance from the crack to make a uniform current flow in the region far from the crack [1]. The closely coupled probes potential drop (CCPPD) technique using four probes, which are in close proximity to each other, has been proposed by Saka *et al.* to enhance the sensitivity of potential drop technique [2], and has been successful for quantitative NDE of small fatigue cracks [3]. The technique measures the surface potential drop between the two measuring probes, where the objective crack is located at the center of the four probes, and therefore, the technique requires the crack location in advance.

The present paper describes an approach to d-c potential drop NDE of small cracks, where the distribution of the surface potential drop around the crack is obtained by scanning the CCPPD sensor. The method is capable of clearly identifying the crack location and enhancing the sensitivity to a great extent, especially for the shallow surface cracks, which, in turn, ensures highly sensitive detection as well as precise measurement of both the depth and length of sub-millimeter surface cracks. The evaluation of the shallow fatigue crack is demonstrated by the present potential drop technique.

2. Experiments

Two types of 3-D surface cracks, namely, the simulated and fatigue cracks were introduced into the specimens that were machined from austenitic stainless steel, AISI304. The 3-D simulated crack was introduced into the plate specimens by electrical discharge machining; the dimensions of the cracked specimen were 201 mm (L) × 50 mm (W) × 15 mm (T), as shown in Fig. 1. The values of crack length, $2a$, and the depth, b, of the simulated crack were 17.5 and 1.5 mm, respectively. The 3-D fatigue crack was introduced by cyclically loading the plate in four-point bending (tension-to-tension) in a dynamic testing machine; the dimensions of the fatigue cracked specimen were 250 mm (L) × 50 mm (W) × 16 mm (T), see Fig. 1. A constant direct current of 1 A was applied to the specimens through the current input and output probes. The distances of the current probes and the potential drop measuring probes were 6 and 3 mm, respectively. The photograph of the CCPPD sensor used in the experiments is shown in Fig. 2. The CCPPD sensor is small and easy to deal with, which, in turn, enables us to scan the cracked surface to measure the potential drop as a function of sensor position. A rectangular coordinate system (x, y) was introduced, with an origin located at the center of the crack. In this paper, the

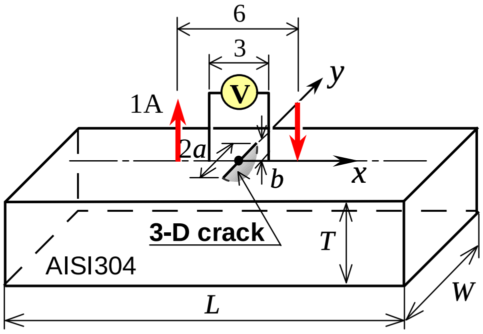

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Figure 1: *Specimens and experimental setup*

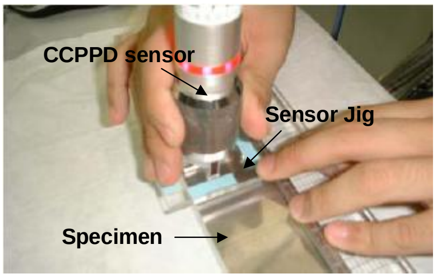

Figure 2: *Photograph of CCPPD sensor*

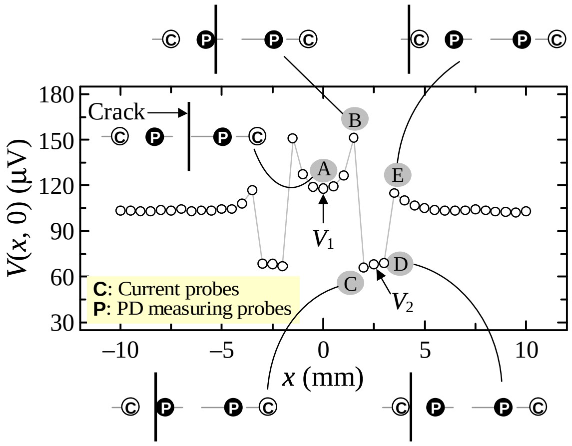

Figure 3: *The potential drop profile along the x-direction for the 3-D simulated crack*

surface potential drop measured as a function of probe position is denoted by $V(x, y)$, where (x, y) is the coordinate at the center of the potential drop measuring sensor, and the units of x, y are in mm. The contact of every probe to the specimen surface was kept under constant pressure by using springs. After the potential drop measurements on the fatigue cracked specimen were performed, the specimen containing the crack was heat treated by an electric furnace for clearly observing the fatigue crack.

3. Results

3.1. 3-D simulated crack

The potential drop profiles along the x-direction, $V(x, 0)$, obtained by scanning the CCPPD sensor on the surface of the simulated crack specimen is shown in Fig. 3. As appears from the figure, the profile is symmetric about the center of the crack (x = 0). Five different peaks of the potential drops, denoted by the points, A, B, C, D and E, as shown in Fig. 3, are observed in the profile, and the corresponding positions of the current and measuring probes are schematically illustrated in the same figure. The point A is obtained when the sensor is located at (0, 0), and this value of potential drop, $V(0, 0)$, can be used for evaluating b. The precise measurements of the potential drops

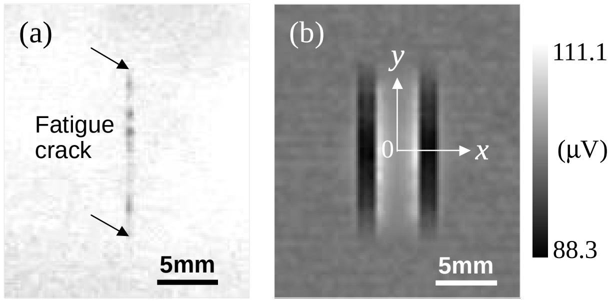

Figure 4: *Photograph of the penetrated fatigue crack (a), and the potential drop distribution at the corresponding area (b)*

at the points B, C, D and E may be difficult because these are obtained at the positions where a potential drop measuring probe or a current probe is very close to the crack. The potential drops observed between the points C and D of the profile have the possibility to be used for NDE of small cracks, because, in this region, neither the potential drop measuring probes nor the current probes are located very close to the crack, and thus the corresponding potential drops can be stably obtained. In this paper, the potential drop, $V(0, 0)$, at the point A is denoted by V_1, and that obtained at a probe position between the points C and D, $V(2.5, 0)$, is denoted by V_2. It is noted that in the earlier studies, only the value of V_1 was used for the evaluation of crack depths. As observed from the potential drop distribution across the crack, V_2 is also attractive for the evaluation of small cracks. Then, the value of $\Delta V = V_1 - V_2$ becomes a powerful parameter for sensitive NDE of small cracks.

3.2. 3-D fatigue crack

The tested 3-D fatigue crack was very difficult to be identified on the plate surface, and the observation of the crack was realized by the penetrant testing. The tested fatigue crack might be tightly closed. The photograph of the fatigue crack identified by the penetrant testing is shown in Fig. 4(a). The potential drop distributions around the fatigue crack are presented as an image of the cracked surface in Fig. 4(b). Here, the scanning pitch of the sensor was 0.5 mm in both x- and y-directions. Figure 4(b) clearly shows the fatigue crack lying in the y-direction. The measured potential drop profile in the x-direction at y = 0 for the fatigue crack is shown in Fig. 5(a). The value of V_1, i.e., $V(0, 0)$, was 101.9 μV. And the value of V_2 was 89.8 μV, which was the average of $V(-2.5, 0)$

[= 90.1 μV] and $V(2.5, 0)$ [= 89.5 μV]. The value of ΔV was thus found to be 12.1 μV. Figure 5(b) shows the potential drop profiles in the *y*-

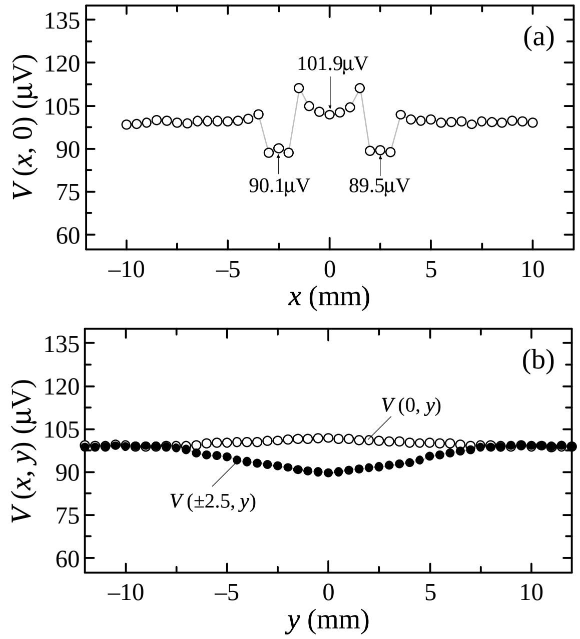

Figure 5: *The potential drop profiles of the fatigue crack in the x-direction (a) and the y-direction (b)*

direction, $V(0, y)$ and $V(\pm 2.5, y)$, for the fatigue crack. Here the profile of $V(\pm 2.5, y)$ is the average of the profiles of $V(-2.5, y)$ and $V(2.5, y)$. The values of $V(0, y)$ and $V(\pm 2.5, y)$ take their respective maximum and minimum values at the crack center ($y = 0$), and these values approach to the potential drop of un-cracked material for positions of the sensor far from the crack.

4. Evaluation of Fatigue Crack

Now if we find the crack tips, where the value of $[V(0, y) - V(\pm 2.5, y)]$ takes 10% of ΔV, the tips of the fatigue crack are located at $y = -7.0$ and 7.0 mm in Fig. 5(b), respectively, and then the value of $2a$ of the present fatigue crack is estimated as 14.0 mm. Figure 6 shows the relationship between ΔV and b obtained by the finite element (FE) analysis. In obtaining the relation, the used value of $2a$ was 14.0 mm as evaluated by the preset technique. The value of ΔV obtained from the experiment was 12.1 μV, and the corresponding value of b of the fatigue crack was evaluated as 0.43 mm from the calibration curve shown in Fig. 6. The photograph of the fractured surface of the fatigue cracked specimen is shown in Fig. 7. The crack length of the tested crack was measured as 13.9 mm. The value of the length evaluated by the present technique (14.0 mm) and that measured were judged to be in good agreement. The value of b at the crack center was found to be 0.429 mm on the fractured surface, and thus the value of b evaluated by the present technique was in very good agreement with the direct measurement.

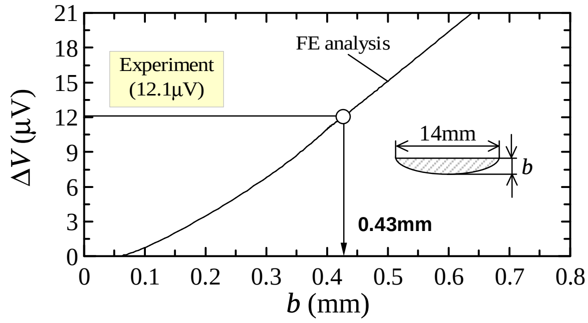

Figure 6: *Calibration curve derived by FE analysis*

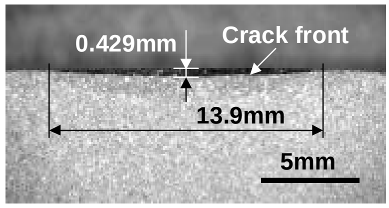

Figure 7: *Photograph of the fractured surface*

In the present study, to realize the quantitative NDE of shallow cracks, the sensor used has narrow spacing between the probes, for example, the current probes and the potential drop measuring probes distances were 6 mm and 3 mm, respectively. Wider space of the four-point probes achieves deeper penetration depth of current [4], and the present technique based on the potential drop profiles measured by the four-point probes is applicable for NDE of wide range of cracks.

5. Conclusions

This paper demonstrated the potential drop imaging technique by the closely coupled four-point probes DCPD sensor for the highly sensitive detection as well as quantitative evaluation of both the length and depth of small surface cracks.

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6. References

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